N88-10095

ELECTRICAL POWER WORKING GROUP REPORT

Gerrit van Ommering, Chairman
Ford Aerospace and Communications Corporation

Ira Myers, Cochairman
NASA Lewis Research Center

1. INTRODUCTION

As indicated in the observations and recommendations of the Spacecraft Systems Working Group, the Electrical Power Subsystem represents a high-leverage area for spacecraft bus mass reduction and resulting payload fraction improvement. While mass reduction benefits all mission types significantly and directly, improvements in several other performance parameters, including deployed area and radiation hardness, are important in specific applications. Life, reliability and cost, while acceptable for current power systems, could be improved and should certainly not regress as low-mass technologies are developed and implemented.

Within this context, the Electrical Power Subsystem Working Group assessed the status of and need for power technologies for Spacecraft 2000 and identified development programs required to establish an achievable and competitive technology base for spacecraft of the 21st century. This report summarizes the results of the Working Group efforts, including recommendations and the underlying rationale.

2. SCOPE AND OBJECTIVES

The missions and spacecraft covered by this assessment were limited to the following primary groups, based on Steering Committee guidance provided at the start of the Workshop:

- GEO Satellites
- GEO Platforms
- Polar Platforms
- Planetary Missions

This mission mix led to selection of 50 kW as the maximum payload power level. This leaves out power systems based SP-100 technology, several SDI missions, and very-high-power planetary spacecraft. Space Station and related systems are excluded since their power hardware is currently being developed, but their contribution to the technology base is recognized.

Other constraints imposed on the scope include that technologies to be considered should have reasonably broad applicability to a range of missions; that unusual power technology requirements for unique missions should receive dedicated development outside the Spacecraft 2000 initiative; and that recommended technologies should have the potential for readiness early in the 21st century.

The overall objectives of the EPS WG study were:

- Identify critical power subsystem needs, issues, and limitations
- Identify promising technologies and their benefits
- Recommend development and validation programs, and possible government/industry roles

3. APPROACH

Because of the diversity of power technologies, and the size of the EPS WG, the group was divided into four panels as follows:

- Power System
- Power Generation
- Energy Storage
- Power Management and Distribution

Each panel independently addressed its area in accordance with the objectives, but periodic brief overall WG reviews were held to provide opportunity for cross-critique, coordination, and discussion. The typical assessment approach for each panel was:

- Identify power subsystem technology selection criteria
- Identify and assess key issues in current technologies
- Define performance limitations of current technologies
- Identify promising new technologies and their benefits
- Assess technology readiness date vs development support
- Determine need for and status of development programs

Several key considerations were used to guide the technology and development requirements assessment, with the underlying goal of maximizing mission- and cost-effectiveness:

- Commercial/NASA/Military design practice differences
- Desirability and feasibility of standardization
- Autonomous operation
- Safety, reliability, and survivability

- o Performance, mass and life vs cost
- o Manufacturability, testability, serviceability, and supportability

4. POWER SYSTEM

The Power System panel addressed broad issues that affect overall power subsystem design, development, implementation, operation, interfaces, and user accommodation. The general areas addressed were:

- o Commercial/NASA/Military practice
- o Power levels
- o User power preferences & needs
- o Source technology applicability
- o Hardware modularity & standardization
- o Serviceability/maintainability
- o Power system test beds
- o Automation technology
- o Orbit and mission factors
- o Operating voltages, dc vs ac
- o Central vs local regulation
- o Topology standardization
- o Growth accomodation
- o Integrated power system modeling
- o Test technology
- o Expert systems applications

4.1 Key Issues Definition

From the above list of items the following key issues were identified which represent needs that are inadequately addressed by current development of power system technology:

Technology Key Issues	Design Philosophy Key Issues
o Automation technologies	o Standardization
o High-voltage (>150 V)	o Modularity for commonality
o Total-system modeling tools and techniques	o Modularity for serviceability and maintainability
o Expert systems technologies	o Utility approach to power distribution
	o Growth capability/compatibility

The technology key issues represent areas where specific hardware and software development is needed. The philosophy key issues are concerned with policy and approach: the general framework and constraints that apply to the development of power system technologies, including power generation, energy storage and power management and distribution hardware.

4.2 Technology Development Recommendations

Automation

Cost effectiveness of future space systems will depend strongly on minimization of real-time spacecraft operation from the ground. As satellite power systems become larger, more sophisticated and optimized, operational complexity is likely to increase. In addition, the detection, diagnosis, correction, and management of fault conditions becomes more complex and demanding. The growing inventory of operational spacecraft will magnify this problem.

Interplanetary missions have a particularly strong need for power system automation because of the long reaction time and resulting increased vulnerability to fault conditions. For earth-orbiting missions automation could be implemented on-board the spacecraft or on the ground via telemetry and command links. The latter approach still involves time delay and is itself vulnerable to interruption and faults. Thus, on-board automation is clearly a necessary technology for Spacecraft 2000, and is viewed as enabling for the larger power systems. It will lower operations cost and risk and improve system performance.

Automation philosophy is being developed for Space Station systems. It is recommended that similar development be conducted on automation for unmanned and non-maintainable space systems, taking advantage, where appropriate, of Space Station data. In particular, the general power system management philosophy should be defined in an initial study. This general approach should cover interplanetary as well as earth-orbiting spacecraft, and a range of power source and energy storage alternatives. As a next step, algorithms and software should be developed and verified in ground-based hardware test bed.

High-Voltage Power Distribution

Low voltage dc power distribution has been used in virtually all spacecraft to date. For the Space Station and related systems, a 20 kHz, 440 V distribution system will be developed. The age-old question of what the best distribution technology is has not been conclusively answered, however, for all applications. The high voltage level on the station is driven primarily by mass of the distribution lines, and 20 kHz ac was selected for mass-efficient conversion to other power types.

For dimensionally smaller spacecraft the distribution of power at the generation voltage, which may be on the order of 200 V for higher-power systems, is quite mass-efficient and little would be gained by conversion to higher voltage ac power for distribution. Individual payloads can then provide local conversion to the specific needs of each payload with efficient, high-frequency converters.

It is therefore expected that significant demand as well as payload customer preference will exist for the foreseeable future for high voltage power systems. Competitiveness in the international marketplace will also likely require the capability for producing these systems. Availability of both ac and dc options would provide a flexible, competitive technology base for Spacecraft 2000.

The recommended development effort would consist of definition of appropriate standards and development/adaptation of devices, switchgear, and conversion equipment for high voltage operation, taking advantage where possible of developments of similar hardware for the photovoltaic subsystem source bus on the Space Station.

System Modeling Tools and Techniques

The increased complexity and size of power systems will make it increasingly difficult to validate system performance prior to hardware fabrication, and will escalate the cost of dedicated test beds for each application. In addition, optimization of the overall system design requires more complete models than currently available.

It is recommended that development be initiated of an integrated power system model that has a high degree of modularity, flexibility, and adaptability. This model would serve as a standard tool for design and analysis of Spacecraft 2000 and related power systems. It would permit detailed iterative analysis and performance evaluation at a very early stage of hardware design. Most initial iterations could then be conducted analytically, so that a significant amount of breadboarding and other developmental hardware efforts could be avoided, with resultant cost savings. The model should be verified on a generic test bed. Combined with a reasonable degree of standardization, this model could significantly reduce the cost of power system design, development, and redesign.

Expert Systems

Expert systems for the management of space power systems are a natural follow-on to the automation and modeling efforts. Automation techniques and software currently envisioned will be limited in their ability to deal with highly complex systems and real-time decision making will not accommodate complex rules. Application of expert systems to the EPS will enable greater operational independence, optimization, and interfacing with higher-level expert systems governing overall spacecraft and payload operations.

While this capability should flow out of the automation and modeling tasks, it is recommended that initial studies be performed to establish a framework of requirements, system management philosophy, and hierarchies applicable to an EPS expert system. This will serve as guidance for the other tasks, so that the eventual transition to expert system development and implementation will be evolutionary in nature, rather than requiring a complete overhaul of the approach.

4.3 Design Philosophy Definition

The design philosophy area addresses issues that do not require specific technology developments, but rather studies to define overall design guidelines for space power systems and components. The main drivers behind these issues are cost-effectiveness in DDT&E, production, and implementation of space power systems, and providing flexible user power.

Standardization and Modularity

The concepts of standardization and modularity are strongly related and must be addressed in an intergrated fashion. It is recommended that studies be conducted to establish guidelines for standardization and modularity based on probable payload power requirements, servicing and maintenance concepts and scenarios, and mission type distribution. These guidelines will necessarily evolve as Spacecraft 2000 systems studies achieve increasing degrees of definition.

Standardization. Several standards exist today for space power systems at low voltage. Similar standards should be developed for higher-power, high-voltage systems to promote cost-effective development and provide guidance to advanced systems planning for Spacecraft 2000 in both payload and bus areas. These standards should be developed in a cooperative, iterative fashion by NASA and industry, and retain sufficient early flexibility to absorb information and refinements from hardware efforts, and other programs such as Space Station.

In hardware development a certain level of standardization should also be considered to improve cost effectiveness. The concept of a modular EPS approach with several standard component sizes should be re-evaluated, and may be feasible for platform-type satellites. To avoid significant mass penalties and unnecessary margins, however, a study should be made of the probable payload power requirements spectrum for Spacecraft 2000, so that the level of standardization and modularity can be intelligently selected.

Modularity for Commonality. This concept concerns selection of EPS components module sizes that by replication can meet the power requirements of individual missions, while minimizing mass penalties and production cost. This concept can even be extended to subassemblies within components.

Modularity for Serviceability/Maintainability. Space systems of the Spacecraft 2000 generation should be designed for maintainability and serviceability. Design of the EPS should allow for normal and safe operation with temporary absence of components during servicing operations, which suggests component module sizing and replication as well as design features and constraints.

Utility Type Power Distribution

The utility approach to power distribution is an important element of ensuring that Spacecraft 2000 power systems have broad applicability and a flexible payload accommodation interface. It implies distribution of one type of power with local regulation and processing at the payloads to suit their specific needs. This will provide a clean, predictable power interface. As part of the standardization studies this approach should be addressed in order to identify specific implementation issues and preferred configurations.

Growth Capability and Compatibility

An integral element of modularity and standardization is the feasibility of growing power subsystems to accommodate additional payloads. This is a natural requirement for multi-payload platforms in particular. Cost-effective growth capability is tied to modularity issues and should be addressed as part of the studies that define the guidelines in that area. Growth accommodation must also be allowed for in the design of EPS components to permit growth with newer technologies alongside still operational older hardware. This established a requirement for "transparency" of technologies: interfaces must be established and defined to isolate the major EPS elements from the peculiar characteristics of interfacing elements. Standardization of power bus performance parameters must consider this very carefully so as not to "shut out" new technologies.

5. POWER GENERATION

The Power Generation Panel considered photovoltaic, solar thermal dynamic, and nuclear power source technologies in the context of Spacecraft 2000 applications. Given the size and types of missions involved, the overall judgement was that the emphasis should be on improvements in photovoltaic technologies.

5.1 Solar Dynamic Systems

In the solar thermal dynamic area, significant development will occur as part of the Space Station program. This may spin off technology that can be scaled down to power levels appropriate for Spacecraft 2000, but specific development should await results of the Station efforts. On-going Stirling engine development should be continued to provide an advanced high-efficiency conversion cycle alternative.

5.2 Nuclear Systems

Nuclear reactor technology may have application in higher-power interplanetary missions. This possibility should be addressed by studying SP-100 derived technology and other small reactor concept designs in the context of projected mission requirements. Hardware development would be conducted most likely outside the Spacecraft 2000 scope since this would be a rather specialized application.

5.3 Photovoltaic Systems

Photovoltaics offers significant potential for improved performance in terms of specific power (W/kg), primarily by decreasing solar cell thickness and by improving array construction technology. Development of high-efficiency cells will provide additional mass leverage. Cost of production can be improved by using large-area cells for silicon or concentrator cells for gallium arsenide (GaAs). Life performance improvements are feasible through the use of advanced cells which are not significantly affected by radiation environments. Specific recommendations will be discussed in more detail below.

Specific programs recommended for consideration under the Spacecraft 2000 initiative are:

- o Lightweight Silicon Array
- o Gallium Arsenide Flight Panel
- o High Efficiency Solar Cells
- o Indium Phosphide Solar Cells
- o Advanced Concentrator Arrays
- o Modular Solar Array

The first two programs form an integrated effort to systematically improve array performance capability by phasing in advanced technology in a logical, timed, but aggressive fashion. They develop hardware based on technology already within reach. The cell programs are directed at device technology R&D and demonstration, with the end product to be eventually retrofitted into the lightweight array technology.

Lightweight Silicon Array

Typical specific power capability of current advanced arrays is about 30 W/lb. A JPL-sponsored program is now underway at TRW to develop technology at the 60 W/lb level through the use of thin cells. The selected configuration uses relatively small cells and significant optimization of the array structure is not part of the program scope. It is strongly recommended that a follow-on program be conducted to incorporate large area cells and perform added optimization of the structure to arrive at about 75 W/lb or better.

Gallium Arsenide Array Technology

GaAs cells have significantly improved efficiency than Si but are currently built at relatively high thickness (12 mil) and thus represent a mass penalty negating the efficiency gain. The potential for improvement will be realized with thin cells. Projected capability with 2-3 mil GaAs cells retrofitted into the lightweight array will be 100 to 110 W/lb. To establish readiness for application in a timely fashion, it is recommended that a two-phase development program be conducted. The first phase would establish and demonstrate GaAs cell laydown, interconnection and assembly techniques using 12 mil cells and flexible array technology, and include thermal cycle testing. The second phase, building on this technology and the lightweight Si array results, would include module fabrication using thin GaAs cells.

High Efficiency Solar Cells

Further improvements in specific power can be obtained from high-efficiency cell technology. Achieving the GaAs efficiency goal of 26% could yield 140 W/lb, and multi-bandgap cells at 30-35% could reach 180 W/lb if they can be produced at competitive thickness levels. NASA should consider funding selected high-potential aspects of this work to accelerate availability of these devices.

Indium Phosphide Solar Cells

Indium Phosphide (InP) solar cells promise exceptional resistance to radiation damage. This can be a significant advantage in particular for polar orbiters. It is recommended that NASA support this technology with research funding to evaluate feasibility, optimization potential, and demonstrate capability for about 18% efficiency and radiation resistance/annealing properties.

Advanced Concentrator Arrays

Concentrator arrays can make the high efficiency of GaAs cells available in terms of area reduction and, while GaAs cells are still expensive, at a potentially reduced cost. Significant power density improvements are less likely with this concept because of the rigidity requirements for the arrays, caused by the tight pointing requirements. It is recommended that NASA maintain current in the technology and conduct specific studies to evaluate whether NASA mission requirements exist that may benefit from the concentrator approach, and conduct appropriate development to support such mission requirements.

Modular Solar Array

Current solar arrays are typically custom designed for the specific application, resulting in significant non-recurring cost. To explore opportunities for cost reduction, a study is recommended of modular solar array concepts, in concert with the power system standardization and modularity studies. The objective should be to define and evaluate approaches to modularization for commonality, maintainability, growth and interface standardization, and establish a module sizing rationale. Study results should verified at the component level and then be fed into lightweight array programs.

6. ENERGY STORAGE

The Energy Storage Panel considered the following energy storage technologies and divided them into the three categories shown below:

Current

- nickel-cadmium
- nickel-hydrogen
- regenerative fuel cell (separate stacks, dynamic transport)

Near Term Advanced

- sodium-sulfur (beta)
- regenerative fuel cell (separate stacks, passive transport)
- rechargeable lithium

Far Term Advanced

- regenerative fuel cell
  - single cell
  - solid oxide
  - anhydrous H2/halogen
- sodium-sulfur (glass)
- lithium batteries
- polymer batteries

- o flywheels
- o tethers

In general, the Panel recommends that NASA place the least emphasis on the current technologies, the most on the near term advanced technologies, and an intermediate amount on the far term advanced technologies. The one exception is a recommendation that NASA emphasize ground testing of nickel-hydrogen cells to a low earth orbit regime because of the importance of the technology to Space Station. The Panel recommended sodium-sulfur batteries and simpler regenerative fuel cells for the most emphasis over the next several years. Finally, the Panel recommends that NASA sponsor moderate and steady research effort among the far term advanced technologies until preferred approaches emerge.

6.1 Current Technologies

These are mature technologies which have either transitioned to operational use, or, in the case of regenerative fuel cell, the major components (fuel cell and electrolysis stacks) are mature and the system is ready for engineering development for specific applications by 1990. The usable specific energies of these technologies range from 3-12 watt-hours/pound (Wh/lb) for nickel-cadmium, to 6-16 for nickel-hydrogen and somewhat higher for regenerative fuel cells.

Nickel-Cadmium Batteries

Nickel-cadmium batteries are the most mature of the technologies considered and are the least likely to yield dramatic improvements in specific energy with further development. The key to improved performance in nickel-cadmium batteries is increased depth-of-discharge for the longer cycle life missions which, in turn, is dependent on improved nickel electrodes. The development of improved nickel electrodes is the object of work sponsored by NASA Lewis Research Center. This work should be continued because it has been productive and is likely to continue to yield the greatest benefit for the least cost.

Nickel-Hydrogen Batteries

Nickel-hydrogen batteries based on IPV (individual pressure vessel for each cell) have transitioned into operational use in high orbits where the limited cycle life requirements make the present limited data base adequate to make the selection. The data base for low orbit use needs to be improved to provide more reliability and confidence level data and to better define cycle life capabilities at various depths of discharge. Since IPV nickel-hydrogen cells have been selected for use on the Space Station, it will be necessary to further develop the data base for low orbit operation. NASA should participate with the Air Force in a low orbit test program already being set up at the Naval Weapons Support Center at Crane, Indiana.

The design and manufacture of IPV cells is fairly well established, although incremental improvements are still being made. The design and manufacture of bipolar modules is incomplete and should be continued if the unique advantage of high rate capability is to be realized.

Improvements in nickel electrodes that would allow deeper depths of discharge could substantially improve usable specific energy, particularly for low orbit missions such as Space Station. Unlike nickel-cadmium cells, nickel-hydrogen cells can also improve their specific energy if the nickel electrodes can be made thicker (e.g. thickness increased from 29-35 mils to 60-80 mils). Again, improvements in both nickel-cadmium and nickel-hydrogen technology depend on improvements in the nickel electrode. Continued investment in nickel electrode technology will yield the greatest benefit at the lowest cost.

Regenerative Fuel Cells (Active Water and Thermal Management)

The critical components (separate fuel cell and electrolysis cell stacks) of a low temperature, hydrogen-oxygen, regenerative fuel cell systems are well established. Engineering development could combine these components into systems (using active components for product water and thermal management) by 1990. The reliability of such systems is suitable for low orbit manned missions where maintenance and resupply are possible. It is not suitable for missions where maintenance and resupply are not possible.

Much of the basis for the development of this system was in anticipation of its use on Space Station. The selection, by Space Station, of solar dynamic and nickel-hydrogen technologies instead, reduces the incentive for near-term development of this approach (i.e. with active components for water and thermal management). There is, however, a basis for further development of low temperature, hydrogen-oxygen regenerative fuel cell systems that use passive means of water and thermal management as discussed in the next section.

6.2 Near Term Advanced Technologies

All near term advanced technologies offer usable specific energies in the range of 25-50 Wh/lb. The technologies of critical components (cells and stacks) have been under development for many years and are well advanced but require further development. They can have technology readiness dates in the mid-1990s if properly supported.

Sodium-sulfur Batteries (Beta Alumina Electrolyte)

Sodium-sulfur batteries have the best combination of high usable specific energy and advanced technology status. The high usable specific energy is the result of three factors: (1) the high specific energy of the cells (75 Wh/lb), (2) slightly higher charge-discharge efficiency than nickel based systems resulting in reduced solar array size and weight, and (3) high temperature operation (350 C) which dramatically reduces radiator size and weight. Individual cells have operated for more than 6000 cycles and for 2-3 years. Adequate calendar life remains to be demonstrated. The main problems are degradation of the beta" alumina electrolyte and corrosion of the container, but progress has been steady in both areas.

The Air Force, after an exhaustive study of other battery and fuel cell alternatives dating back to 1979, has selected sodium-sulfur for their next generation space battery. The Air Force program is comprehensive, covering cells and batteries for high and low orbits. Work by NASA in the sodium-sulfur battery area should be carefully coordinated with the Air Force to prevent duplication of effort.

Regenerative Fuel Cells (Passive Water and Thermal Management)

There are concepts for, and some demonstration of, low temperature, hydrogen-oxygen regenerative fuel cell systems which use passive techniques of water and thermal management. Systems based on passive water and thermal management techniques have the potential for the higher reliabilities needed for use in unmanned missions. If these techniques can be implemented in lightweight hardware, specific energies comparable to sodium-sulfur and rechargeable lithium batteries should result. In addition, hydrogen-oxygen regenerative fuel cells offer higher peak power capability than either of the batteries and the possibility of further weight savings by integration with other spacecraft systems such as hydrogen-oxygen propulsion.

The Panel recommends that NASA continue development of regenerative fuel cells emphasizing passive techniques of water and thermal management.

Rechargeable Lithium Batteries

Various lithium-based rechargeable batteries offer high specific energy at potentially low cost and with cycle life suitable for high orbit missions. Small commercial cells of less than one ampere-hour capacity already offer about 25 Wh/lb and up to 3000 cycles. Lithium-metal sulfide cells offer 32-42 Wh/lb. Higher specific energies are likely with development. The Energy Storage Panel did not have a lithium battery specialist, and does not make specific recommendations in the lithium battery area.

6.3 Far Term Advanced Technologies

The far term advanced technologies generally have the potential for very high usable specific energies - some greater than 50 Wh/lb, but have technology readiness dates of 2000 or beyond. The development of virtually all has been slowed mainly by materials problems. Due to the nature of the materials problems involved, it is difficult to predict where future development might lead to a breakthrough in device practicality. Nevertheless, these technologies represent the most likely sources of advanced energy storage systems for the next century.

The Panel did not have specialists in the areas of lithium batteries, polymer batteries, flywheels of tethers; and does not make recommendations specific to individual technologies in these or the other areas. The Panel does recommend that NASA sponsor a broad and stable, moderately funded program of investigation of these, and possibly other, far term advanced technologies to provide a technology base for future developments.

7. POWER PROCESSING, MANAGEMENT AND DISTRIBUTION

The Power Processing, Management and Distribution Panel was concerned with the following general types of issues:

Distribution Power

- AC, Frequency & Voltage
- DC, Voltage
- Architecture
- Multiple Buses

Component Technology

- High Voltage
- High Power
- Semiconductors
- Capacitors

User Interface

- User-Friendly
- Standardization

Protection Devices

- RPCs
- Hybrid Switchgear

Processing Technology

- Converters and Inverters
- Packaging Technology

Automation

- Hardware
- Software

The conclusions and recommendations in this area are consistent with, and in some cases overlap, those of the Power Systems Panel.

Recommended technology areas for development and study under Spacecraft 2000 auspices are:

- Primary power distribution - high voltage data base
- High power, high voltage switch gear
- Power system automation technologies
- AC distribution system component development
- Integrated analog/digital devices

It is recognized that many of these technologies are planned to be developed as partof the Space Station program. Significant benefit should be derived from those efforts since they push the technology to higher power levels and greater degrees of automation. However, it is generally recommended that NASA assess the suitability of the Space Station designs and hardware to the needs of more specialized, unmanned, and potentially non-maintainable vehicles that may be part of the Spacecraft 2000 family. It is expected that significant upgrades in mass and reliability performance will be desirable and possible. Appropriate development programs should be undertaken to accomplish these upgrades by the late 1990s.

Primary Power Distribution - High Voltage Data Base

Distribution of power at high voltage reduces the size and mass of the harness, a significant benefit for higher power missions. For Space Station the high-voltage dc power source bus operates at a conservative 160-200 V; higher voltage, although desirable, was avoided because of the lack of firm data on plasma interactions. In general, the available data are limited, conflicting, and strongly dependent on test technique.

With the broader application of high voltage dc and ac systems it is essential that sufficient credible data be accumulated to help define limits of operation, component design considerations and margins, and support selection of optimal architectures. With such a data base, full advantage of the safe operating range can be taken with resulting greater benefit. It is recommended that a comprehensive effort be undertaken to establish this data base, including flight tests as appropriate.

High-Voltage Switch Gear

High-voltage switch gear is not currently available for high reliability space applications. High-voltage spacecraft will require programmable, resettable solid state remote power controllers for power system management, fault isolation, and reconfiguration.

While such elements are now baselined to be developed on the Space Station program, they will be primarily directed at its high power levels only, without optimization for medium power levels and highly mass-critical spacecraft. To ensure that optimized high voltage ac and dc switch gear are available for the Spacecraft 2000 generation, specific development and optimization for medium power levels is recommended. Such efforts should take full advantage of Space Station switch gear technology development, and make next-generation improvements in device capability and reliability.

Power System Automation Technologies

Automation technologies will be driven by autonomy and survivability needs. Automatic monitoring of Power Subsystem performance and performing self-test operations will be an essential element of greater spacecraft autonomy. Virtually all automation will be accomplished via software, with only those items still hardwired that require immediate response, such as fault isolation functions. Software-based automation will allow use of standardized hardware, which can be programmed and reprogrammed for suitable operating parameters and limits.

Key hardware elements of automation are sensors and built-in test equipment (BITE). These must be developed for general purpose spacecraft applications beyond technology planned for Space Station. It is recommended that NASA conduct detailed studies of requirements for sensors and power subsystem BITE for Spacecraft 2000 with Space Station technology as a baseline and conduct further development to extend that technology to Spacecraft 2000 needs.

AC Distribution System Components

AC distribution at 20 kHz has been baselined for the Space Station program. It is expected that larger spacecraft will use distribution systems based on this technology. For moderate power levels, optimization of transmission line design and reduction of connector mass and complexity are particularly important to the viability of ac power on future spacecraft. Impedance behavior of ac harnesses in complex networks also requires further understanding, along with better test, modeling and simulation techniques.

These areas should be explored with Space Station technology as a point of departure, defining improvements and optimization required for broader satellite application, and appropriate development efforts to achieve readiness by the year 2000.

Integrated Analog/Digital Devices

Automation of power subsystems requires extensive interfacing of analog and digital devices to form the link between analog sensors and data/control functions. High-frequency power conversion using discrete components is complicated due to uncontrolled parasitics. Integration of analog and digital devices on a single chip is important to minimizing mass and volume as well as parasitics and other interference problems. Analog/digital device integration development is proceeding in commercial applications, but does not address several aspects that are key to successful space devices, such as thermal control, isolation, and multiple power device topologies.

It is recommended that NASA conduct a study to develop topologies for integrated analog/digital devices appropriate to applications in spacecraft power subsystem components. These topologies should cover multiple on-chip power structures, on-chip optical interfacing, and thermal management approaches. Development of prototype devices for test and evaluation should follow to establish readiness for flight hardware development by the early 1990s.

8. ADDITIONAL RECOMMENDATIONS

8.1 Flight Tests

It is recommended that brief flight tests, most likely on the STS Orbiter, be conducted to characterize plasma interactions with high voltage power subsystem elements, such as solar arrays and distribution lines. No strong necessity is seen for extended flight tests in the near future.

8.2 Terrestrial Test Beds

Establishment of a terrestrial electrical power system test bed is seen as a high priority item. This test bed should have the flexibility and modularity to accept hardware of different power ratings and types. Its purpose will be the experimental verification of new devices and hardware concepts, as well as software for power system control. Adaptation of test bed efforts being undertaken for the Space Station program should be considered, for cost effective implementation of the proposed flexible test bed.